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DEVELOPMENT AND EVALUATION OF THE DRINKING WATER QUALITY INDEX IN THE EASTERN BANK OF NINEVEH GOVERNORATE

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EXTENDED ABSTRACT

Obiettivo di questo studio è il tentativo di sviluppare un nuovo metodo per valutare l'indice di qualità delle acque sotterranee (GWQI) derivato dall'equazione di Gupta & Misra, 2018.

Tale indice si basa sugli standard indicati dall'Organizzazione Mondiale della Sanità (OMS, 2006) (GWQI 3) e sulle specifiche standard irachene di potabilità (IQS 417, 2001) (GWQI.6) per la valutazione delle acque sotterranee e la possibilità di utilizzo delle acque dei pozzi per uso potabile nella zona orientale del fiume Tigri, nel Governatorato di Ninive.

Per'un'attenta valutazione sono stati quindi selezionati tre siti: il primo tra la città di Mosul e Jabal Bashiqa, il secondo tra i distretti di Hamdaniya, Bartella e Nimrod, ed il terzo tra la città di Tel-kaif e la città di Wana.

Complessivamente, per misurare 12 parametri e calcolare l'indice di qualità dell'acqua (GWQI), che comprende: le proprietà fisiche, il pH, i sali totali disciolti (TDS) e la conducibilità elettrica (E.C.), sono stati prelevati centotrentanove campioni di acqua di pozzo.

Le proprietà chimiche misurate in laboratorio includevano i cationi (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), gli anioni (SO_4^{2-}, HCO_3^{-}, Cl^{-}, NO_3^{-}) ela durezza totale (TH).

I valori ottenuti di qualità dell'acqua in termini di GWQI. 1 variavano da 20 a 271, quindi l'acqua dei pozzi è stata classificata come non potabile nel 43% dei casi, di pessima qualità potabile nel 28%, di scarsa qualità nel 27% e di buona qualità solo nel 2% dei campioni esaminati. Mentre i valori del proposto GWQI. 2, derivato dall'equazione originale, dopo aver eliminato i paramentri che non influiscono sulla qualità dell'acqua potabile, vale a dire pH, K^{+} e HCO_3^{-}.variavano tra 66 e 172.

Secondo la classificazione di Gupta & Misra (2018), la maggior parte dei campioni, per il 59%, mostrava una qualità dell'acqua molto scarsa, scarsa nel 12%, potabile solo nel 29%, mentre la categoria buona ed eccellente non è stata trovata.

Utilizzando la formula proposta GWQI. 3 e la classificazione in funzione dei limiti del WHO, (2006), il 37% dei pozzi risulta non potabile, il 57% con acqua molto scadente, il 6% scadente, mentre non si riscontrava la categoria buono e ottimo.

Il GWQI. 4 variava da 24 a 374 per le specifiche standard irachene (IQS 417. 2001), nei seguenti rapporti: 10%, 18% e 72%, rispettivamente scarso, molto scarso e inadatto. Mentre il proposto GWQI. 5 secondo gli standard IQS 417. (2001) variava tra 80 e 268, con i campioni distribuiti in molto scadente nel 19% e inadatta all'uso potabile nell'81%.

Infine, applicando l'equazione e la classificazione proposta GWQI.6 è stato trovato che il 68% dei pozzi erano non potabili, il 30% con qualità molto bassa e il 2% con qualità bassa. Il motivo per cui i pozzi presentavano valori di GWQI molto alti era probabilmente legato al forte aumento delle concentrazioni di potassio provenienti dai fertilizzanti organici e chimici utilizzati in agricoltura.

In generale, le acque sotterranee nell'area di studio risultano non adatte per usi potabili e domestici.

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ABSTRACT

Groundwater quality is the result of all the chemical and hydrological reactions and processes that affected on the water. The Water Quality Index (WQI) is a mathematical tool that describes water quality to assess the levels of water usage. This study attempts to develop a new method for the groundwater quality index (GWQI). It is based on the standards of the (WHO, 2006) and the (IQS 417, 2001) to assess the groundwater and validity of wells water for drinking in the eastern bank of Nineveh Governorate. 139 well water samples were taken to measure 12 physical variables (pH, E.C. and T.D.S.) and chemical variables (Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^2, HCO_3^{2-}, Cl^-, NO_3^-, and T.H.). Nine variables were use to calculate the WQI, excluding non-influential parameters (potassium, pH, and bicarbonate) that fall within the permissible ranges for drinking in WHO and IQS 417, based on the statistical treatments.

The study developed and modified equations and classifications were used to reflect an accurate quality of the groundwater in the region. The (GWQI.3) classified depending on (WHO, 2006), 37% of wells were unsuitable, 57% were very poor, 6% were poor, while the (GWQI.6) was classified as follows: 68% are unsuitable, 30% very poor, 2% poor, depending on (IQS 417, 2001).

In general, groundwater in the study area is unsuitable for drinking and civil uses.

Keywords: *water quality, WQI, groudwater, drinking water, Mosul, Nineveh Governorate*

INTRODUCTION

Groundwater is a renewable natural resource of clean water because it has the sufficient levels of the nutrients needed for health in comparison to surface water (Udeshani *et alii*, 2022). Groundwater quality is the outcome of all processes and interactions that impact water, from when it condenses in the atmosphere to when it is released from a well; therefore, determining groundwater quality is essential for monitoring water suitability for a particular use. Groundwater quality data give significant evidence to the geological history of rocks and indicators of groundwater recharge, movement, and storage (Walton, 1970). Groundwater quality depends on many factors, such as the type of rocks and minerals pH functions that can interact with water, the stratigraphic and structural position of the aquifer layers, and the physical characteristics of the aquifer rocks, Such as porosity, permeability, depth, degree of chemical weathering of prevailing rocks, quality of feeding water and inputs from other sources (Schuh *et alii*, 1997; Hussein, 2004). Time changes in the origin and composition of recharged water, hydrological and human factors often cause cyclical changes in groundwater quality (Milovanovic, 2007; Aghazadeh & Mogaddam, 2010, Medici & Langman, 2022).

WQI is a mathematical tool that describes the water quality at a certain level (Bordalo *et alii*, 2006); the water quality index was defined by Li *et alii*, (2014) as determining the appropriateness of the studied area concerning drinking, and this includes calculating the total hardness and concentrations of the main cations and anions present in water. Each of them is analyzed by chemical analysis, other physical variables such as the hydrogen ion, electrical conductivity, and total dissolved salts were field-measured, and determine the acceptable limits for all variables by the World Health Organization or the standard specifications of that country, meaning it describes the quality of water with a specific number (Sun *et alii*, 2016).

THE LOCATION OF THE STUDY AREA

Nineveh Governorate is located in the northern part of Iraq. The study area is located east of the Tigris River within the eastern side of Nineveh Governorate and its nearby suburbs. It is bordered on the west by the Tigris River, on the northeast by Ain Sifni Mount, and on the southeast by the Greater Zab River, located between 36°45’00” N to 36°7’30” N Latitude and 42°45’00” E to 42°30’00” E Longitude. The study area is approximately 4110 km^2, surrounded by several mountains on the east and north side. It is represented in the first region between Mosul city and Bashiqa and Al-Fadiliyah, located near the northern border of the region, the Bashiqa mountain; its height is approximately 699 meters above sea level, which represents the Bashiqa and Al-Fadiliyah folds. The second study area lies between the Tigris River in the west mount and southwest, the Greater Zab River in the southeast, Al-Khazir tributary in the northeast, and Ain-sifnie mountain in the northeast the north, which includes the Hamdaniyah district. The area descends, in general, from the north towards the Tigris River. While the third study area is located between Talkaif and Wana Town and is about 50 km northwest of Mosul city, Some wells situated in the flood plain of the Tigris River are fed by the waters of the Tigris River, as well as a large number of wells that provided by the Tigris River (Fig. 1).

GEOLOGICAL SETTING

The geological, structural, stratigraphic, lithology and geomorphological conditions control the hydrogeological elements spatial distribution and extensions, such as aquifers and aquitards, and their hydrogeological characteristics. The first area includes Mount Bashiqa, which consists of Bashiqa and Al-Fadiliya anticline located east of Mosul city, the axis of the two folds is oriented northwest-southeast (Al-Jumaily & Al-Azzawi, 2018) and consists of dolo-limestone rocks and dolomite. The Hamdaniya area is characterised by its terrain topography, and it is undulating towards the southwest, gradually to a low slope. The Wana area is one of the areas near the Tigris River represented by the geological aspect of the deposits of river

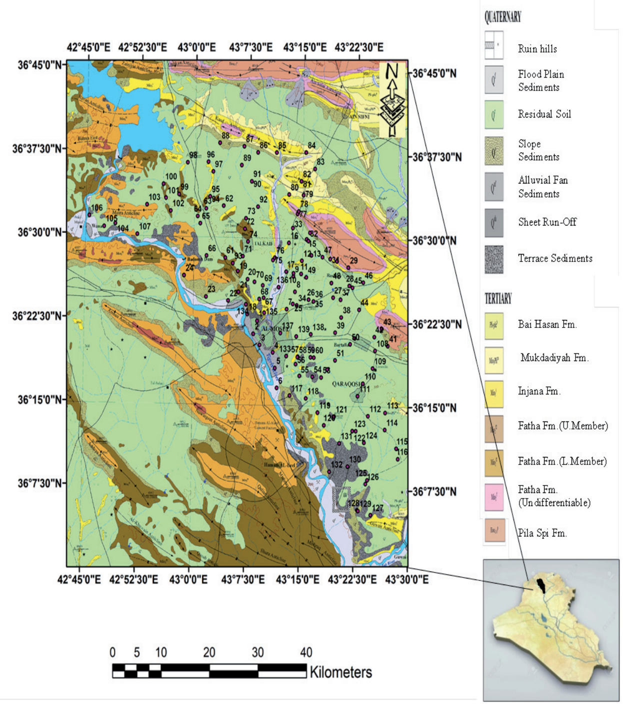


Fig. 1 - A geological map Mosul city (Talkaif, Bartalla, Wana, Bashiqa and Qaraqosh) showing the locations of the wells

terraces (Al-Dabbagh & Al-Naqib, 1991). The importance of studying geological formations of their impact on the properties of groundwater that passes through them, as well as their effect on the hydrochemical and movement of groundwater. The Pila Spi Formation (Middle-Upper Eocene) is revealed in all the syncline folds in the northeastern corner of Nineveh Governorate. The Fat'ha Formation (Middle Miocene) is widely exposed in almost all anticline folds. It is also exposed within the syncline folds. It is composed of gypsum, limestone, and marl. Injana Formation (Upper Miocene) can be well distinguished in the core of some synclines and the troughs of some anticlines, it periodically consists of sandstone, siltstone, and claystone. The Muqdadiyah Formation (Pliocene) is revealed in the basins of some concave folds, especially within the northeastern parts and on the two ends of some syncline folds, it consists of gravel sandstone, sandstone, siltstone, and mudstone. The Bi Hassan Formation (Pliocene) consists of conglomerates, mudstones, and sandstones. The sediments of the Quaternary age (Pleistocene) consist of sediments of river terraces alluvial that can be distinguished along the two banks of the Tigris River, they consist mainly of gravel; the cement material is sand, silt, and clays. The residual soils (Pleistocene-Holocene) are of a sandy type or loam soil and sometimes contain gypsum. Sediments of the flood plain (Holocene) can be observed on the banks of the Tigris River, consisting of sand, silt, and clay

The structural geology of the area is located mainly within the unstable shelf represented by the high and low fold range zones (Chamchamal, Butmah, Makhoul, Hamrin zones) and partly within the stable shelf represented by the Salman and Al-Rutbah - Al-Jazirah zones (Fouad, 2015).

CLIMATIC CHARACTERISTICS

The hydrogeological conditions of groundwater reservoirs are directly affected by the climatic elementss of the area of these reservoirs, as rainwater is the main source of recharge for these reservoirs, which in turn is a reflection of other metrological characteristics (Ullah et alii, 2022). Nineveh Governorate is characterised by the fact that its climate follows the Mediterranean system, which is characterized by a semi-arid in summer and rainy periods in winter, that helps in dry agriculture; the annual amount of rain reaches 375-425 mm, which is suitable for feeding groundwater by falling rain and sometimes snowfall (Al-Qassab, 1987). The study area is within a relatively large rain-gaining area that led to feeding the groundwater, in addition to the large number of catchment valleys extending from the mountainous regions towards the site. Abdullah (2010) stated that rain is not considered acidic except in polluted areas with a high overcrowding population, cars, and generators inside neighbourhoods. However, it tends to be below 7, and this is due to (CO_2) gas, which is primarily present naturally in the atmosphere (Mahmood *et alii*, 2006).

PREVIOUS STUDIES

Al-Salim & Matte, (2009) studied groundwater quality for domestic and agricultural uses in selected areas of northeast of Mosul City, where the result was, in general, that the waters of the site are classified as fresh-hard water to saline and slightly alkaline. The study (Al-Hayali, 2010) showed that the wells' water was hard to very hard, depending on the essential determinants of domestic purposes; most of the wells' water was unsuitable for drinking and industry. (Al-Ozeer & Ahmed, 2019) assessed groundwater quality in the eastern side of Mosul city for various purposes during 2014-2017 by studying the physical, chemical, and biological properties of the shallow wells distributed in residential areas. The results showed that the studied groundwater samples are not valid to drink and unsuitable for crops sensitive to salt. The wells among Mosul, Bashiqa, and Fadiliya towns were classified by (Al-Youzbakey & Sulaiman, 2020) as poor to very poor and unsuitable for drinking purposes, based on WQI values (56.1-98.4). The classification using the Cohen network that was used by (Taha & Hussein, 2011) is one of the methods of smart techniques to classify wells in groups according to the percentage of electrical conductivity in the aquifer located within the PilaSpi Formation in the Bashiqa area. Regarding the many uses of that water, the majority of them are acceptable for irrigation, followed by the findings of their research (Taha & Hussein, 2012), which were suitable for drinking and agricultural as one of the six types utilizing the cluster analysis approach.

The chemical analyses by (Al-Yousbakey *et alii*, 2018) in the Mosul-Bashiqa-Shallalat area resulted in two groups of wells; the first group affected the dissolution process of the components of the Fat'ha Formation rocks, which led to an increase in their concentrations. The second group falls within the recent sediments that control the low concentrations of ions, which is suitable for domestic uses and irrigation better than the first. (Al-Naqib *et alii*, 2018) the study hydrochemical conducted on groundwater and its levels fluctuation between 2009-2011 areas of the eastern side of the city of Mosul showed that there was a general decrease in the levels of the Injana Formation wells and the river terraces, It may be related to the scarcity of rainwater, which led to the absence of no significant changes in the hydrochemical characteristics compared to the previous ten years. The WQI study was addressed by many researchers, including a comparison of all water quality indicators within the framework of the study carried out by (Tyagi *et alii*, 2013), taking into account their advantages and disadvantages. After studying the different water quality indicators, it can be inferred from the computational water quality index method that the goal is to give a single value for the water quality of the source water along with reducing a larger number of parameters in a simple expression which leads to an easy interpretation of the water quality control data. Many countries have developed their own WQI in several arid and semi-arid countries; Morocco, Iran, Pakistan (Asadi *et alii*, 2019; El Mountassir *et alii*, 2022; Ullah *et alii*, 2022 and Udeshani *et alii*, 2022) and there are some Iraqi attempts on this subject concerning surface water. Al-Youzbakey and Sulaiman (2021) studied the drinking water quality index and concluded that the fluctuation of the concentrations of the cations and anions is due to the impact of the source rocks and the soil derived from them by chemical weathering.

THE STUDY AIMS

The study aims to develop a new method for the groundwater quality index (GWQI) using well data from the region and based on WHO (2006) standards, and the Iraqi standard specifications for drinking water (IQS 417, 2001), find a new classification of groundwater quality based on the prevailing effective ions and determine the general features of the areas for well exploitation.

MATERIALS AND METHODS

Sampling and analyses

139 samples were taken from well water in the studied area to measure the pH function, total dissolved salts (TDS) and electrical conductivity (E.C.) in the field by a portable device of the type (hold)/T.D.S.-3 meter. The samples were stored in 1000 ml capacity bottles of Polypropylene inside a refrigerator at 4C° cooler (Walton, 1970). It was filtered to get rid of suspended impurities to be transferred later to the Geochemistry Laboratory at Dams and Water Resources Research Center at the University of Mosul to measure each of the calcium ion (Ca^{2+}), magnesium (Mg^{2+}) and total hardness (T.H.) by titration with EDTA as a guide, the concentration of both sodium ions (Na^+) and potassium (K^+) was measured by using a flame absorption spectrometer (PFP7 Flame Photometer) tape GENWAY. The Chloride (Cl^-) was measured by titration with silver nitrate $AgNO_3$ solution and bicarbonate ions HCO_3^{2-} by titration with $H_2SO_4^{2-}$.

The sulfate ions ($SO_4^{2-)}$ and nitrate ion NO_3^- were measured by (UV-Spectrophotometer) tape of OGAWA, OSK7724. Use deionised water to dilute standard solutions and dilute samples (Souad & Hassan, 1990; Federation, 2012). As for the statistical treatments of the data set, the programs Microsoft® Excel 2010 and IBM® SPSS® V.22 were used. The Principal Component Analysis (P.C.A.) method was used to determine the most effective water quality parameters and their relative weights.

Method

The GWQI was calculated according to Gupta & Misra (2018) method depended on the variables pH, TDS, E.C, T.H, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, HCO_3^{2-}, Cl^- and NO_3^- by using the equation (1):

$$GWQI = \sum n_{i=1} Q_i \cdot W_i / \sum W_i \qquad (1)$$

where,

Qi =100·[Measured value (V_m) - Ideal value (V_i)]/[Standard value (V_s) - Ideal value (V_i)], sub-index for ith water quality parameter; $V_{m\,-}$ Measured value of the water samples for quality parameters estimated from analysis, V_i - Ideal value of that water quality parameter can be obtained from the standard tables, Ideal value is equal to zero for most parameters except for pH function = 7 and *F* = 1.0 mg/L, V_s - Standard of the water quality parameter given by WHO (2006) and IQS 417 (2001) (Table 1).

$W_i = K/S_i$, S_i - Standard value for nth parameter, *K* = Proportionality constant = 1.

The general approach was summarised in 6 steps by (Kannel *et alii*, 2007).

1. Choosing the appropriate water quality standards.
2. Weight assignments.
3. Configure sub-indicators by converting the concentration of variables into equations.
4. Finding the final form of the equation.
5. Finding an appropriate classification for drinking water quality based on the maximum permissible limits according to (WHO, 2006) and (IQS 417, 2001).
6. Apply them to the study data to verify their accuracy and correctness.

Parameter	Vs (WHO,2006)	Vs (I.Q.S./417,2001)
pH (unit)	7-8.5	6.5-8.5
T.D.S (mg/l)	1000	1000
E.C (µS/cm)	1400	2000
T.H (mg/l)	500	500
Ca^{2+} (mg/l)	75	50
Mg^{2+} (mg/l)	50	50
Na^{+} (mg/l)	200	200
K^{+} (mg/l)	55	----
Cl^{-} (mg/l)	250	250
HCO_3^{-} (mg/l)	400	-----
SO_4^{2-} (mg/l)	400	250
NO_3^{-} (mg/l)	50	50

Tab. 1 - Standards for drinking water according to (WHO, 2006) and (IQS 417, 2001)

Parameter	Minimum	Maximum
pH (unit)	6.80	8.5
T.D.S (mg/l)	246.00	9321
E.C (µS/cm)	152.00	4381
T.H (mg/l)	213	4429
Ca^{2+} (mg/l)	22	900
Mg^{2+} (mg/l)	10	563
Na^{+} (mg/l)	4.00	1500
K^{+} (mg/l)	0.30	275
HCO_3^{-} (mg/l)	59	659
SO_4^{2-} (mg/l)	30	5100
Cl^{-} (mg/l)	1	1932
NO_3^{-} (mg/l)	56	856

Tab. 2 - Minimum and maximum for the water variables in the studied wells

parameter	Component		
	1	2	3
E.C.	0.731	0.635	
TDS	0.736	0.639	
T.H	0.956		
Ca^{2+}	0.844		
Mg^{2+}	0.684		
Na^{+}		0.777	
K^{+}			0.673
HCO_3^{-}			0.795
SO_4^{2-}	0.973		
Cl^{-}		0.847	
NO_3^{-}		0.551	
% of Variance	52.69	11.98	10.69
% of Cumulative variance	52.69	64.64	75.34

Tab. 3 - The matrix and the total amount of variance of the three factors after rotation

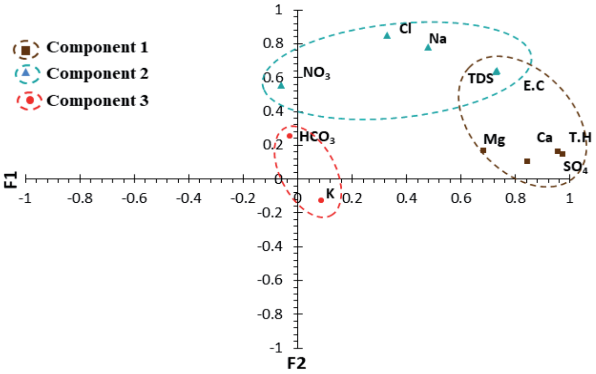


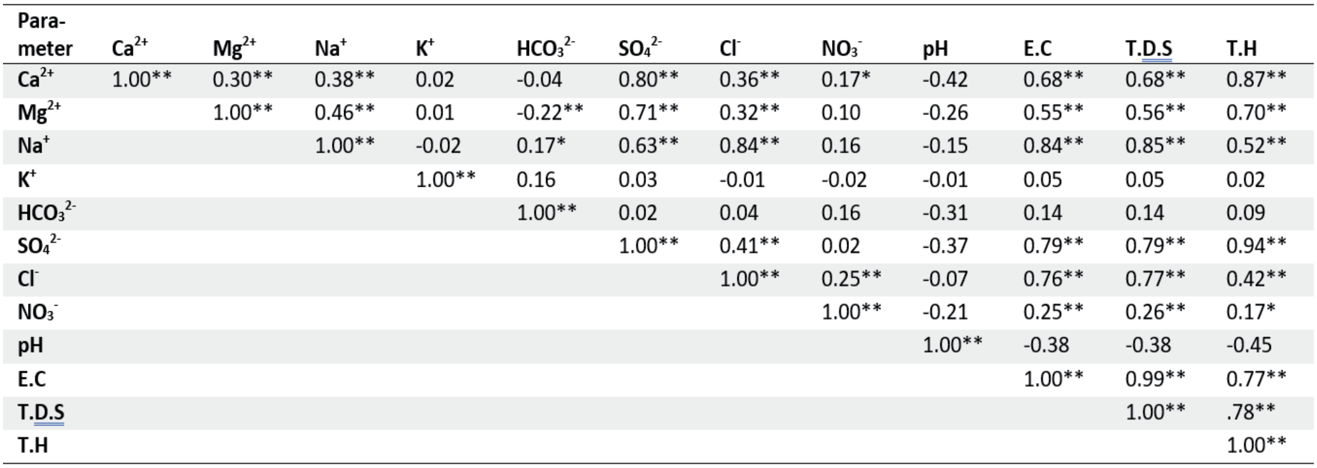
Fig. 2 - The distribution of ions according to the first and second factors after rotation, represent the component 1: the effect of rock types of reservoirs, component 2: the effect of the dissolving of secondary minerals soil surface, and component 3: the effect of weathering reaction on the carbonate rock fragments in the soil

RESULTS

Twelve variables were selected for the quality of water, including the pH function, T.D.S, E.C, T.H, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, HCO_3^{2-}, Cl^{-} and NO_3^{-} due to their importance and their overall impact on water quality Table 2, using the method of P.C.A. The main method (P.C.A.) is a well-known technique for analysing multiple variables in a way that allows identifying patterns in the data series to find out the similarities and differences without losing many variables (Chu *et alii*, 2018). The results of P.C.A. are presented in Table 3, which indicates the selection of three main components with a cumulative variation of 75.34%, the first factor represents 52.97% of the variance and the second factor is 11.98%, while the third factor represents 10.69% of the total variance Table 3 and Fig. 2.

According to P.C.A., common denominators are considered if they are greater than 0.5+, and based on which the variables capable of constructing the W.Q.I. equation are selected (Ewaid *et alii*, 2019; Sahoo *et alii*, 2015; Zeinalzadeh & Rezaei, 2017). All variables have common denominators greater than 0.5. One of the methods of statistical analysis used is the correlation analysis and the chemical data analysis using the R-Mode Factor Analysis, Table 4.

The first factor accounts for 52.97 percent of the total variance. There were a strong direct relationship between the



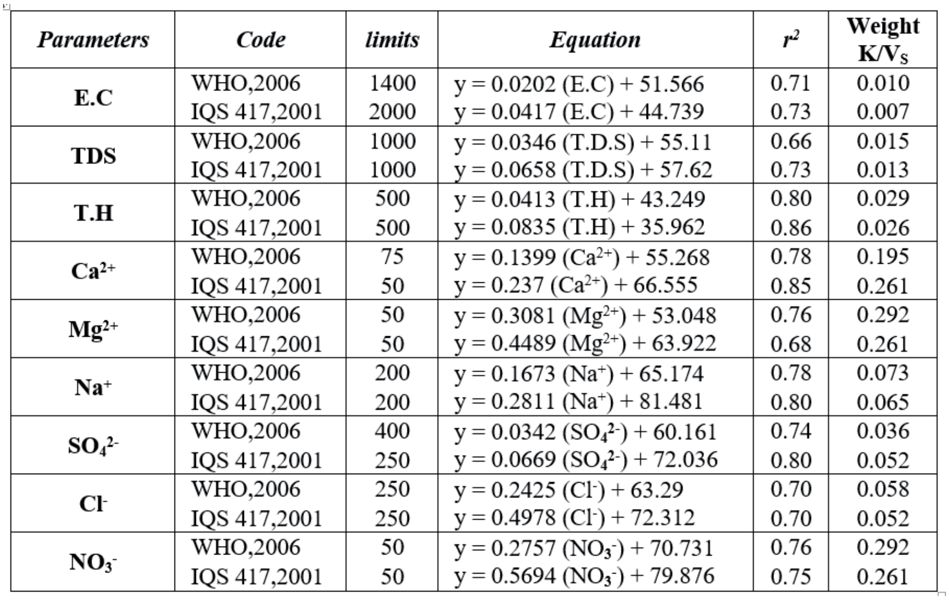
Para-meter	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^{2-}	SO_4^{2-}	Cl^-	NO_3^-	pH	E.C	T.D.S	T.H
Ca^{2+}	1.00**	0.30**	0.38**	0.02	-0.04	0.80**	0.36**	0.17*	-0.42	0.68**	0.68**	0.87**
Mg^{2+}		1.00**	0.46**	0.01	-0.22**	0.71**	0.32**	0.10	-0.26	0.55**	0.56**	0.70**
Na^+			1.00**	-0.02	0.17*	0.63**	0.84**	0.16	-0.15	0.84**	0.85**	0.52**
K^+				1.00**	0.16	0.03	-0.01	-0.02	-0.01	0.05	0.05	0.02
HCO_3^{2-}					1.00**	0.02	0.04	0.16	-0.31	0.14	0.14	0.09
SO_4^{2-}						1.00**	0.41**	0.02	-0.37	0.79**	0.79**	0.94**
Cl^-							1.00**	0.25**	-0.07	0.76**	0.77**	0.42**
NO_3^-								1.00**	-0.21	0.25**	0.26**	0.17*
pH									1.00**	-0.38	-0.38	-0.45
E.C										1.00**	0.99**	0.77**
T.D.S											1.00**	.78**
T.H												1.00**

$^*p < 0.05$, $^{**}p < 0.01$

Tab. 4 - Correlation coefficient matrix for groundwater variables in the study area

aforementioned variables so they are present together in the first factor, comprising SO_4^{2-}, T.H, Ca^{2+}, TDS, E.C., and Mg^{2+}. The range of sulfate reached (30-5100) ppm Table 2. It was found in Table 3, the highest value in the first factor was for sulfate, which is (0.973) and included with Mg^{2+}, and the highest value of the correlation coefficient is the relationship of SO_4^{2-} with T.H and it is (r^2=0.943). This is evidence of the dominance of permanent hardness in the wells of the study area. This factor represents the effect of rock type of reservoirs on the chemical properties of the well's waters.

The second factor constitutes (11.984)% of the total variance and is represented by the positive loading of (E.C, TDS, NO_3^-, Na^+, and Cl^-) elements. The Cl^- concentration reached from (0.01-1932.99) ppm, Table 2, a strong direct relationship was observed between the variables, so they are present collectively in the second factor, Na^+, TDS, E.C, and NO_3^-, Table 3, its coefficient of strong correlation with each of Na+, E.C and TDS, it participates in a part of the total dissolved salts and electrical conductivity of water, Table 3, so it was included in



Parameters	*Code*	*limits*	*Equation*	*r^2*	Weight K/V_S
E.C	WHO,2006 IQS 417,2001	1400 2000	$y = 0.0202\ (E.C) + 51.566$ $y = 0.0417\ (E.C) + 44.739$	0.71 0.73	0.010 0.007
TDS	WHO,2006 IQS 417,2001	1000 1000	$y = 0.0346\ (T.D.S) + 55.11$ $y = 0.0658\ (T.D.S) + 57.62$	0.66 0.73	0.015 0.013
T.H	WHO,2006 IQS 417,2001	500 500	$y = 0.0413\ (T.H) + 43.249$ $y = 0.0835\ (T.H) + 35.962$	0.80 0.86	0.029 0.026
Ca^{2+}	WHO,2006 IQS 417,2001	75 50	$y = 0.1399\ (Ca^{2+}) + 55.268$ $y = 0.237\ (Ca^{2+}) + 66.555$	0.78 0.85	0.195 0.261
Mg^{2+}	WHO,2006 IQS 417,2001	50 50	$y = 0.3081\ (Mg^{2+}) + 53.048$ $y = 0.4489\ (Mg^{2+}) + 63.922$	0.76 0.68	0.292 0.261
Na^+	WHO,2006 IQS 417,2001	200 200	$y = 0.1673\ (Na^+) + 65.174$ $y = 0.2811\ (Na^+) + 81.481$	0.78 0.80	0.073 0.065
SO_4^{2-}	WHO,2006 IQS 417,2001	400 250	$y = 0.0342\ (SO_4^{2-}) + 60.161$ $y = 0.0669\ (SO_4^{2-}) + 72.036$	0.74 0.80	0.036 0.052
Cl^-	WHO,2006 IQS 417,2001	250 250	$y = 0.2425\ (Cl^-) + 63.29$ $y = 0.4978\ (Cl^-) + 72.312$	0.70 0.70	0.058 0.052
NO_3^-	WHO,2006 IQS 417,2001	50 50	$y = 0.2757\ (NO_3^-) + 70.731$ $y = 0.5694\ (NO_3^-) + 79.876$	0.76 0.75	0.292 0.261

All parameters in (mg/l), except E.c. in (μS/cm)

Tab. 5 - The derived mathematical equations of the (y=GWQI) for the studied wells according to (WHO, 2006) and (IQS 417, 2001) with the weights assigned to the nine parameters

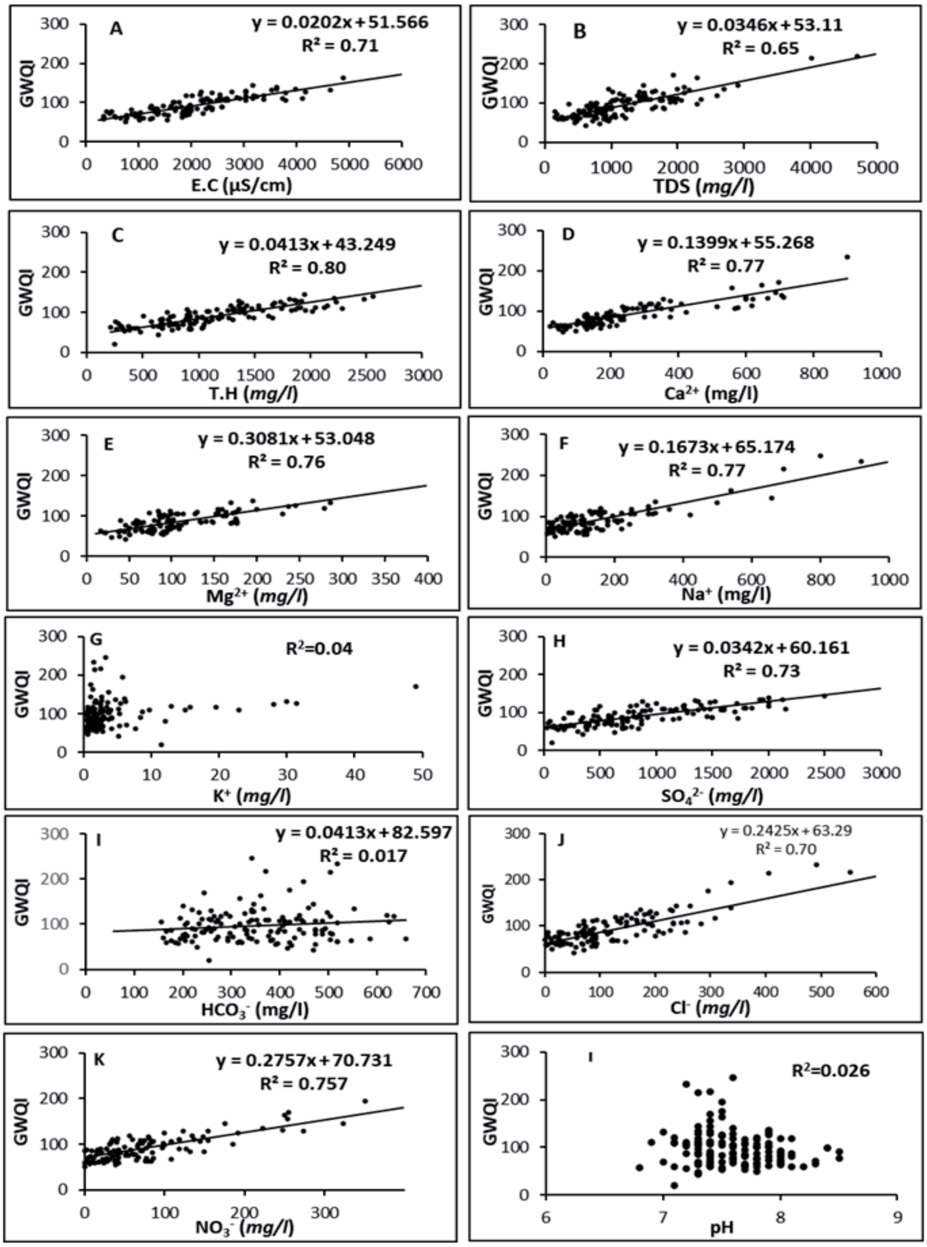


Fig. 3 - The relationships and Corellation coefficients of Water quality index (GWQI) Vs the 12 variables according to (WHO, 2006)

the two proposed equations to develop the groundwater quality equation for drinking (GWQI) because it has a high and positive correlation coefficient according to (r^2=0.704) (WHO, 2006) and (IQS 417, 2001) (r^2=0.702) Figs. 3 and 4 Table 5. This factor represents the effect of the dissolving of secondary minerals that precipitated by capillary activity in the soil surface.

The third factor constitutes (10.697)% of the total variance, represented by the positive loading of elements (HCO_3^- and K^+).

The highest value was for bicarbonate, and then for potassium, its correlation coefficient with the rest of the variables is represented by a weak relationship in Table 4. This factor represents the effect of weathering reaction on the carbonate rock fragments that present in the soil.

Table .5 shows the Weight customization that given to the variables to indicate the importance of each variable and its impact on the quality of groundwater in the region.

The configured sub-indicators transform variables depending on their importance and their impact on water quality

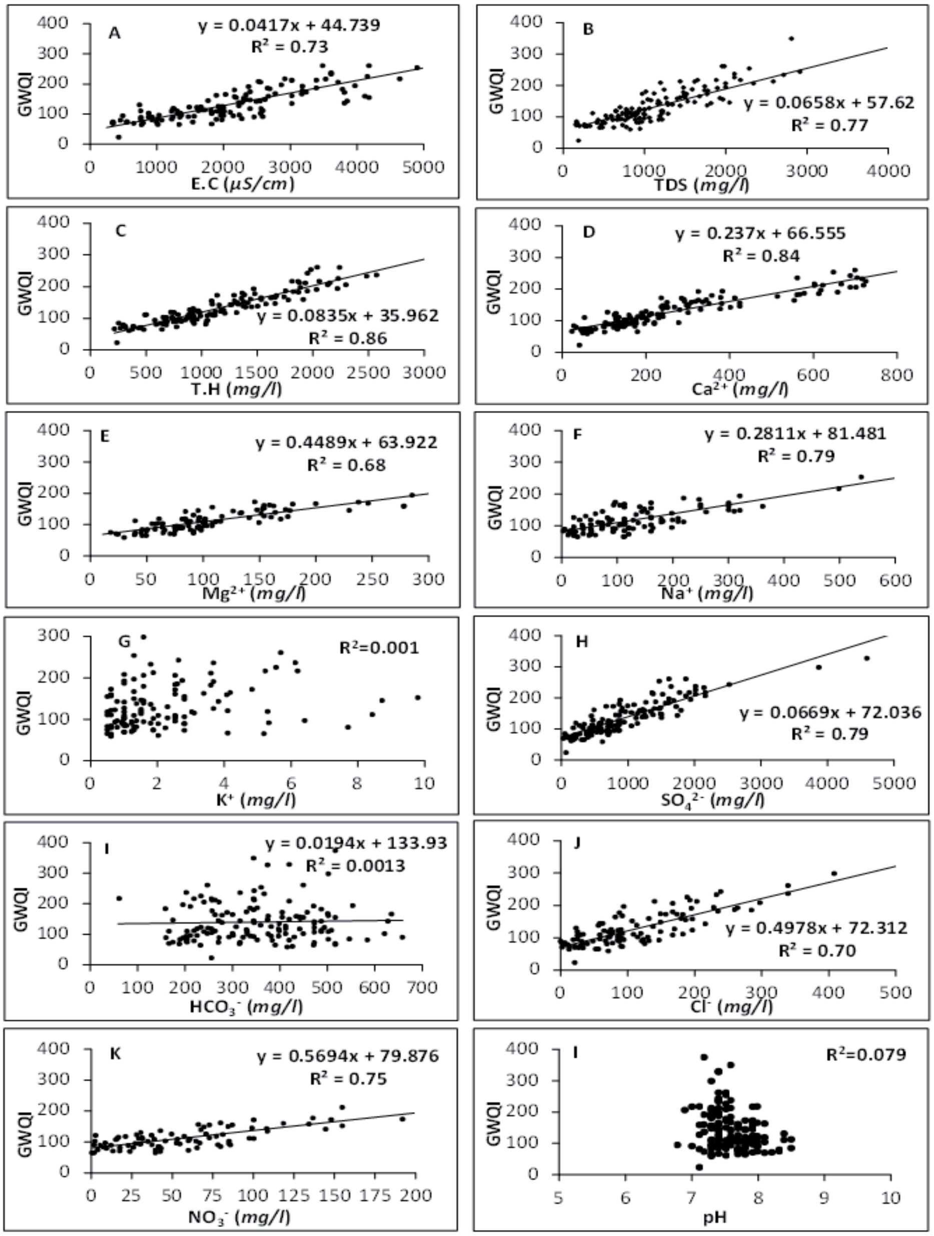
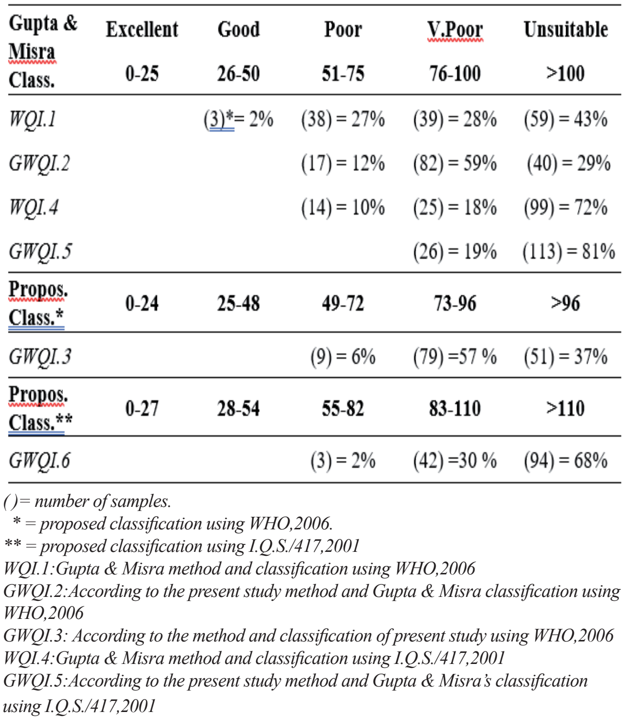


Fig. 4 - The relationships and Corellation coefficients of Water quality index (GWQI) Vs the 12 variables according to (IQS 417, 2001)

(Kachroud *et alii*, 2019 and Rana & Ganguly, 2020). The mathematical expressions for each variable found to derive the sub-indicator equation as shown in Table .5. To develop the sub-variables, they were plotted with the (GWQI) Figs. 3 and 4.

Applying the suggested equation and categorization from Figs. 3 and 4, nine variables: TDS, E.C, T.H, Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{2-}, Cl^{-}, and NO_3^{-} were taken to suggest the new proposed (GWQI) equation based on the significant correlation of WQI among the earlier variables, and three variables (pH, K^{+} and HCO_3^{-}) were excluded, because there is no clear relationship between them and the original drinking water quality equation. World Health Organization (WHO, 2006) and the Iraqi Standard Specifications (IQS 417, 2001) gave suitable water parameters for all uses, Table 1. Two developed groundwater equations were proposed by grouping the sub-variables according to Figs.3 and 4 and Table 5.

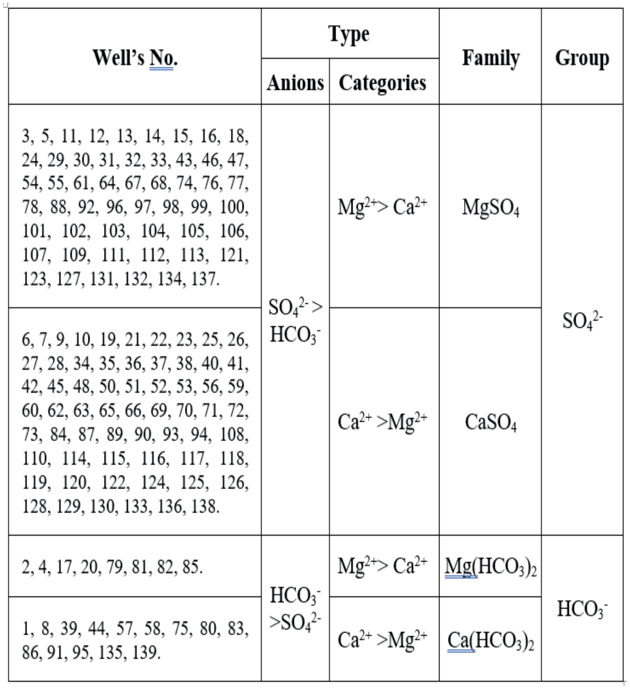
The final result of the formula used for the groundwater quality index was found by grouping the sub-variables as follows:



Gupta & Misra Class.	Excellent 0-25	Good 26-50	Poor 51-75	V.Poor 76-100	Unsuitable >100
WQI.1		(3)*= 2%	(38) = 27%	(39) = 28%	(59) = 43%
GWQI.2			(17) = 12%	(82) = 59%	(40) = 29%
WQI.4			(14) = 10%	(25) = 18%	(99) = 72%
GWQI.5				(26) = 19%	(113) = 81%
Propos. Class.*	**0-24**	**25-48**	**49-72**	**73-96**	**>96**
GWQI.3			(9) = 6%	(79) =57 %	(51) = 37%
Propos. Class.**	**0-27**	**28-54**	**55-82**	**83-110**	**>110**
GWQI.6			(3) = 2%	(42) =30 %	(94) = 68%

( )= number of samples.
** = proposed classification using WHO,2006.*
*** = proposed classification using I.Q.S./417,2001*
WQI.1:Gupta & Misra method and classification using WHO,2006
GWQI.2:According to the present study method and Gupta & Misra classification using WHO,2006
GWQI.3: According to the method and classification of present study using WHO,2006
WQI.4:Gupta & Misra method and classification using I.Q.S./417,2001
GWQI.5:According to the present study method and Gupta & Misra's classification using I.Q.S./417,2001
GWQI.6: According to the method and classification of present study using I.Q.S./417,2001

Tab. 6 - Shows the results and categories of water quality from the original equation and the results of the two developed equations with the developed classification



Well's No.	Type		Family	Group
	Anions	Categories		
3, 5, 11, 12, 13, 14, 15, 16, 18, 24, 29, 30, 31, 32, 33, 43, 46, 47, 54, 55, 61, 64, 67, 68, 74, 76, 77, 78, 88, 92, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 109, 111, 112, 113, 121, 123, 127, 131, 132, 134, 137.	$SO_4^{2-}>HCO_3^-$	$Mg^{2+}>Ca^{2+}$	$MgSO_4$	SO_4^{2-}
6, 7, 9, 10, 19, 21, 22, 23, 25, 26, 27, 28, 34, 35, 36, 37, 38, 40, 41, 42, 45, 48, 50, 51, 52, 53, 56, 59, 60, 62, 63, 65, 66, 69, 70, 71, 72, 73, 84, 87, 89, 90, 93, 94, 108, 110, 114, 115, 116, 117, 118, 119, 120, 122, 124, 125, 126, 128, 129, 130, 133, 136, 138.		$Ca^{2+}>Mg^{2+}$	$CaSO_4$	
2, 4, 17, 20, 79, 81, 82, 85.	$HCO_3^->SO_4^{2-}$	$Mg^{2+}>Ca^{2+}$	$Mg(HCO_3)_2$	HCO_3^-
1, 8, 39, 44, 57, 58, 75, 80, 83, 86, 91, 95, 135, 139.		$Ca^{2+}>Mg^{2+}$	$Ca(HCO_3)_2$	

Tab. 7 - Groundwater quality according to the prevailing cations and anions

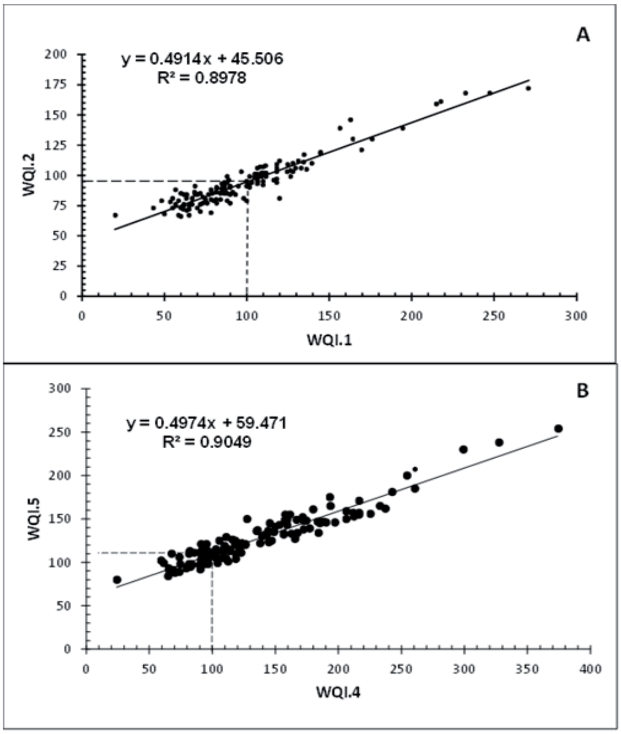


Fig. 5 - The limits of proposed classifications, (A): according to WHO (2006); (B): according to IQS 417 (2001)

$$(GWQI)/(WHO,2006)=[(0.020\cdot(E.C))+51.56)\cdot 0.010+((0.041\cdot(T.H))+43.25)\cdot 0.029+((0.14\cdot(Ca^{2+}))+55.27)\cdot 0.195+((0.31\cdot(Mg^{2+}))+53.05)\cdot 0.292+((0.17*(Na^{+}))+65.17)\cdot 0.073+((0.03\cdot(SO_4^{2-}))+60.16)\cdot 0.036+((0.24\cdot(Cl^{-}))+63.29)\cdot 0.058+((0.28\cdot(NO_3^{-}))+70.73)\cdot 0.292+((0.04\cdot(TDS))+49.03)\cdot 0.015] \tag{2}$$

$$(GWQI)/(IQS417,2001)=[(0.04\cdot(E.C)+44.74)\cdot 0.007+((0.08\cdot(T.H)+35.96)\cdot 0.026+((0.237\cdot(Ca^{2+})+66.56)\cdot 0.261+((0.45\cdot(Mg^{2+})+63.92)\cdot 0.261+((0.28\cdot(Na^{+})+81.48)\cdot 0.065+((0.07\cdot(SO_4^{2-})+72.04)\cdot 0.052+((0.49\cdot(Cl^{-})+72.31)\cdot 0.052+((0.57\cdot(NO_3^{-})+79.88)\cdot 0.261+((0.08\cdot(TDS)+51.4)\cdot 0.013] \tag{3}$$

Any water source is classified into several categories according to the uses of that source. These categories are based on the maximum permissible limits according to (WHO, 2006) and (IQS 417, 2001), with the classification of (Gupta & Misra, 2018), Table 6.

The GWQI classification of groundwater has been proposed to consist of 5 categories which are excellent, good, poor, very poor, and unsuitable for drinking.

The results summarizzed in table 6 of the original equation (Gupta & Misra, 2018) (GWQI.1) ranged between (20-271) according to (WHO, 2006) and distributed as unsuitable for drinking 43%, very poor water quality 28%, poor water quality 27%, four wells of good quality by 2%; were compared with the results of the developed and proposed equation (GWQI.2) which derived from the original one ranged from (66-172) after deleting the non-affecting variables (pH, potassium and bicarbonate) on the drinking water quality in the study area, according to Gupta classification, the majority prevailed for very poor by 59%, unsuitable for drinking by 29%, poor by 12%.

The values of the equation (GWQI.4) ranged from (24-374) according to (IQS 417, 2001) and appeared in the following ratios: 10%, 18%, 72% (poor, very poor, and unsuitable) respectively. The distribution of the categories for the suggested equation (GWQI.5) was 19% very poor and 81% unsuitable, according to Gupta & Misra (2018) classification based on (IQS 417, 2001).

Due to the mismatch between the values of the GWQI.1 and GWQI.2, Table 6. a new provided equation for this study based on (WHO, 2006) by plotting the GWQI.1 and GWQI.2 which represent the equation 4 with (r^2= 0.89). Therefore the study considered to create a new classification limitations that suits the study area, the value approval GWQI = 96 equivalent to WQI = 100 in Gupta & Misra (2018) classification, Fig. 5-A.

$$GWQI = 0.4914\cdot 100 + 45.506 \quad (4)$$

By applying the equation 2 which represent GWQI.3 and the developed classification; it was determined that 37% of the wells are unsuitable, 57% are very poor, and 6% are poor, Table 6, when the (WHO, 2006) limits are used to determine the GWQI for wells dispersed over the eastern bank of Nineveh Governorate.

On the same basis, the relationship between GWQI.4 and GWQI.5 was drawn and a linear equation (listed as equ. 5) with (r^2 = 0.905), Fig. 5-B.

$$GWQI = 0.4974\cdot 100 + 59.471 \quad (5)$$

Through this equation, the same limits were mentioned above was 110 that equfilent to 100. According to the proposed categorization and using equation 3 which represent the GWQI.6; 68% of the wells are unsuitable, 30% are very poor and 2% are poor. This proposed classes for classifying water in the eastern bank of Nineveh Governorate utilizing (IQS 417, 2001) are displayed in Table 6.

DISCUSSION

The pH is a chemical property used to measure the acidity level of water, which is an indicator of the presence of pollutants in the water, where its level varies according to the amount of the original substances (Chapman, 2021), and is one of the variables that enter into the water quality equation.

Their values in the study areas ranged from 6.8-8.5, Table 2, due to the variation in the well water content of bicarbonate that controls pH values, in addition to what gets into the water from the components of calcite and dolomite rocks, which serve to balance the acidity of the water, (Manahan, 2010) so it is within the permitted and safe variables. In order to compare the results obtained from the water quality equation when using default values for the pH that falls within the same permissible range (6.5-8.5) (WHO, 2006) for drinking water, the original Gupta equation was applied to calculate the quality of drinking water using the values taken from the field. When using a pH of 7.5, the variance across the water quality classes was 46 samples out of 139 samples, (about 33%), demonstrating the water fluctuations are inaccurate when using pH as a trustworthy variable to calculate the WQI. Health Canada Organization has found that there is no evidence of adverse health effects directly from the pH on drinking water. However, worrisome indirect health effects related to reduced treatment efficacy, and reduce the disinfection materials activeties or cuse corrosions of pipes that relased Pb, Cu, Cd and Zn to the water (NSE, 2022).

When applying the above according to the specifications of (IQS 417, 2001), which found that there were difference values between the resulting water quality classes reached 34 samples out of 139 samples, with a rate of up to 24%. As for the relationship of the pH with the rest of the variables of the first component, it was weak and negative, Table 4.

The SO_4^{2-} contains the highest concentrations in these wells water due to the high solubility of sulfate in gypsum within the Fat'ha Formation more than HCO_3^-, and it will affect directly and/or indirectly. The secondary minerals of sulphate and halite which resulting from the erosion of the source rocks of Fat'ha Formation that consist of gypsum and halite (Al-Dabbagh & Al-Youzbakey, 2021). Directly on the concentration of HCO_3^-, since sulfur compounds inhibit the activity of aerobic microorganisms to produce carbon dioxide (Sawyer & McCarty, 1978) it is corrosive and has a bitter taste and putrid smell caused by the emission of hydrogen sulfide gas (NSE, 2022). The products of erosion and chemical weathering of gypsum are found within the soil and surface sediments in the water feeding with low percentages of sulfates (Al-Youzbakey & Sulaiman, 2012), and led to raising its concentration in the porosity, medium temperature, continuous feeding by rainwater, the period of exposure of rocks to water in addition to the speed and pressure of water (Tóth, 1970).

It has been included in the two proposed equations to develop the groundwater quality equation for drinking (GWQI) because it has a high and positive correlation coefficient with the original drinking water quality equation (r^2=0.738) according to the standards (WHO, 2006) and (IQS 417, 2001) (r^2=0.796) Table 5, Figs. 3 and 4, and equ. 2 and 3.

Groundwater is often characterized by high hardness, and the main elements responsible for it are Ca^{2+} and Mg^{2+} salts such as HCO_3^-, SO_4^{2-}, and Cl^-. Calcium salts are often the main cause of hardness, other ions play a secondary role. It has become generally accepted that the hardness is defined as the sum of Ca^{2+} and Mg^{2+} concentrations, after calculating the T.H values in the wells of the study area. It was found that it ranges from (212-4429) ppm Table 2. From Table 3, it was found that the contribution of the TH in the first factor is 0.956, and thus it is the second largest component in this factor. The highest value of its correlation coefficient with sulfate in Table 4, for this has been entered into the two equations proposed to develop the groundwater quality equation for drinking GWQI, because it has a high and positive correlation coefficient with the original drinking water quality equation (r^2=0.802) and (r^2=0.861) based on (WHO, 2006) and (IQS 417, 2001), respectivelly, Figs. 3 and 4 and equ. 2 and 3, Table 5.

The type of hardness prevailing in the study area according to the number of prevalent ions according to Table 7. Perpetual hardness is predominant by 83% in the wells of the study area. It is caused by the sulfate ion combined with the Ca^{2+} and Mg^{2+} ions in the water. This is due to the nature of the geological formations through which the water passes, the source of these sulfates from the dissolving of the rocks of the Fat'ha Formation, and temporary hardness appeared at a rate of by 17% in the wells of the study area Table 7.

The HCO_3^- caused ion combined with the Ca^{2+} and Mg^{2+} ions coming from the dissolution of Pila Spi carbonate phases (calcite and dolomite or calcareous rock fragment) in the soil, as well as the components of the soil derived from the eroded rocks in the area, whose weathering products are transmitted by surface water and leached into the soil, thus raising the concentrations of some ions in the wells. The calcium ion, the most concentrated element in groundwater due to the abundance of limestone rocks in the upper layers, is responsible for the hardness of water that affects the daily uses of humans. The concentration of calcium in natural sources of water, especially groundwater, ranges from (10-100) ppm (Kožíšek, 2003), and the extent of calcium in the study area reached (22.44-900) ppm Table 2. The highest correlation coefficient value was with the total hardness and sulfate in Table 4, which was entered into the two proposed equations to develop the groundwater quality equation for drinking (GWQI) because it has a high and positive correlation coefficient according to (WHO, 2006) (r^2=0.776) and (IQS 417, 2001) (r^2=0.848) Figs. 3 and 4 and the equ. 2 and 3, Table 5. TDS are one of the important factors affecting water quality (Mohammed *et alii*, 2018 and Mohammed & Ismail, 2021). It consists of mainly inorganic salts, and the concentrations in water vary significantly in different geological regions due to differences in the solubility of minerals. The TDS in the study area ranged from (152-4381) ppm Table 2; it is related to a strong positive direct relationship with each of SO_4^{2-}, T.H, Ca^{2+}, E.C and Mg^{2+} Table 3, it was entered in the two proposed equations to develop the equation of groundwater quality for drinking GWQI because it has a high and positive correlation coefficient (r^2=0.668) according to (WHO, 2006) and (r^2=0.77) according to (IQS 417, 2001) Fig. 3 and 4, and the equ 2 and 3, Table 5. The relationship of this variable with the rest of the variables is a strong positive direct relationship, except for K^+, HCO_3^-, NO_3^- and pH, Table 4, and this indicates a decrease in the concentration of these salts within the TDS increases as a result of the rainfall and the washing of salts on the soil surface, which leaching into the groundwater and raises the concentration of salts, especially the early stages of the precipitation. Where the rain falls continue, it works to dilute the water, but the first reason is the most impactful. E.C is the solution's ability to conduct electric current and is a function of the level of dissolved salts in the water. The electrical conductivity values of groundwater range between (50-50.000) (μS/cm) in general (Sanders, 1998).

In the study wells, it reached (246-9321) μS/cm, Table 2, and its correlation coefficient is strong with all variables except K^+, HCO_3^-, NO_3^- and pH, Table 4. So, it was included in the two proposed equations to develop the groundwater quality equation for drinking GWQI because it has a high correlation coefficient and positivity according to (WHO, 2006) (r^2=0.713) and (IQS 417, 2001) (r^2=0.738) Fig. 3 and 4 and the equ. 2 and 3, Table 5.

Magnesium (Mg^{2+}) is usually less abundant in water than Ca^{2+}, which is easy to understand as magnesium is found in the Earth's crust in much smaller amounts than calcium. The extent of magnesium concentration in the study area was (11-563) ppm Table 2. The concentration of magnesium is related to a strong positive direct relationship with each of the variables of the first factor Table 3; its correlation coefficient is weak with all variables except for SO_4^{2-}, E.C, T.H, TDS and Na^+, Table 4, so it was included in the two proposed equations to develop the groundwater quality equation for drinking (GWQI) because it has a high and positive correlation coefficient according to (WHO, 2006) (r^2=0.764) and (IQS 417, 2001) (r^2=0.682) Fig. 3 and 4 Table 5, and the equ. 2 and 3. The source of the magnesium ion in the waters of the study area is the dolostones and Mg-limestone. These varying proportions were produced in the content of the mineral.

Chloride (Cl^-) is the most water-soluble anion. It is easily washed out of the upper soil by dissolving the secondary salts of sodium and potassium chloride (NaCl and KCl) by water runoff. The leaching process through the deeper soil areas was the reason for its limited presence. As for the capillary property, secondary halite salts are deposited on the surfaces of the soil, both properties work oppositely, leaking into the deep and shallow groundwater system, and from other sources of chlorine, it is dissolved in rainwater and coming from domestic activity (Souad & Hassan, 1990). Chlorine is one of the elements that remain in its ionic state permanently in water and move over large distances, so it isn't easy to participate in precipitation reactions (Mason, 1966). The concentration of Na^+ in the study area was from (4-1500) ppm, Table 2; sodium is associated with a strong positive direct correlation with both

Cl^-, TDS, E.C and NO_3^-, Table 3, its strong correlation coefficient with Cl^-, SO_4^{2-}, E.C, T.H. and TDS, Table 4, so it was included in the two proposed equations to develop the groundwater quality equation for drinking (GWQI) because it has a high and positive correlation coefficient according to (WHO, 2006) (r^2=0.776) and (IQS 417, 2001) (r^2=0.797), Figs. 3 and 4. Sodium exhibits two different behaviors, evidence that it comes from two sources. The first behavior, accompanied by chlorine, is evidence of its coming from the halite mineral found in the evaporite rocks within the Fat'ha Formation or from the rock fragments in the soil, where rain plays a role in the activities of washing and continuous dissolution of salts, as it leaches through the soil to the subsurface storage rocks, which is the common behavior, the second behavior it does not accompany chlorine where the relationship is random evidence of the arrival of sodium from sewage subtracts, participates in a portion of the total soluble salts and the electrical conductivity of water. The concentration of NO_3^- from (0.50-856) ppm Table 2, the nitrate concentration is related to a positive relationship with Cl^-, Na^+, TDS, and E.C, Table 3, its correlation coefficient with all the variables is Weak relationship Table 4, it has considered into the two proposed equations to develop the groundwater quality equation for drinking GWQI because it has a high and positive correlation coefficient according to (WHO, 2006) (r^2=0.757) and (IQS 417, 2001) (r^2=0.750) Fig. 3 and 4, Table 5. Nitrate is derived from fertilizers, plant rot, and animal waste. These are assumed to be the primary sources of nitrogen compounds in the soil that end up directly and/or indirectly in the groundwater. The concentration of nitrates in groundwater should not cross the 50 ppm limit (Hammill & Bell, 1986). Most of the nitrates in the environment are from organic sources resulting from animal waste raised in agricultural and inorganic areas, such as waste disposal and synthetic fertilizers (E.P.A., 2014 and WHO, 2016).

The concentration of HCO_3^- (58.56-658.8) ppm, Table 2, which represents the (Total Alkalinity) in groundwater. The main source of it in groundwater is the weathering of calcium and magnesium carbonates in limestone and dolostone found in the Pila Spi Formation, where the total alkalinity is a measure of bicarbonate HCO_3^-, carbonate $CO_3^=$ and hydroxyl OH^- dissolved in water (Gill, 2014), the pH did not exceed the limit (8.3) for most wells except for wells (54, 82, 84 and 88), this did not qualify them to precipitate carbonates (Davis & Dewiest, 1966). The low concentration of potassium is due to the adsorption and fixation by clay minerals. Although the abundance of potassium in the Earth's crust is similar to sodium, its presence in groundwater is less than one-tenth of the sodium concentration, and its concentration in groundwater is usually less than 10 mg/l (Hammill & Bell, 1986). The potassium concentration ranges from (0.3-275) ppm in Table 2, which is present with bicarbonate within the same component, but they have no relationship to the source. Potassium shows a weak relationship with all the variables in Table 4. The sources of potassium may be the clay minerals (e.g., illite) within halides in evaporite rock, industrial wastes, and wastewater create potassium minerals such as sulfite in evaporite rocks. Still, their contribution is unimportant, and potassium can come from the decomposition of Chemical fertilizers (N,P,K); this is only available in wells with high concentration, as, in well No. 125, it is beneficial for plants.

Potassium and bicarbonate were not included in the two proposed equations to develop the groundwater quality equation for drinking (GWQI) because they do not have a positive correlation coefficient with any of the variables, and there is no clear relationship between them with the original water quality equation according to (WHO, 2006) and (IQS 417, 2001) Figs. 3 and 4.

CONCLUSIONS

Stabilization of the desired characteristics in the wells of the study area with a clear impact on the quality of drinking water, except the non-affected, fall within the permissible range for drinking, such as potassium, bicarbonate, and pH.

1. Derivation of the equation for drinking water quality from 139 wells. These equations represented the most important variables that have been entered as having an effective impact on the equation of drinking water quality in the studied area.
2. When the pH varies within the range that is safe for drinking according to (WHO, 2006) and (IQS 417, 2001), there is a variation of 33% and 24%, respectively, in the water quality classes of the analyzed wells.
3. Based on the quality of water in these wells, a classification for the drinking water quality in the study area was suggested. Less than 24 is excellent, (25-48) is good, (49-72) is poor, (73-96) is very poor, and more than 96 is unsuitable; this was applied to the studied wells. It was confirmed that the water is unfit for drinking in a percentage distributed as follows: 6% is poor, 57% is very poor, and 37% is unsuitable for drinking according to (WHO, 2006). According to the (IQS 417, 2001), the proposed classification is; less than 27 is excellent; (28-54) is good; (55-82) is poor; (83-110) is very poor and more than (110) is unsuitable, therefore, 2% of the wells are are poor, 30% are very poor, and 68% are unsuitable.
4. 83% of the wells of the study area are dominated by

permanent hardness caused by the sulfate ion combined with the calcium and magnesium ions in the water. The percentage of calcium sulfate in the wells is 45%, and magnesium sulfate is 38%.

5. Most wells are unsuitable for drinking after using the proposed equations and classification

REFERENCES

Al-Janabi S. H. & Saadi A. G. (1992) - *Iraq's Regional Geography*, Dar Al-Kutub for Printing and Publishing, Mosul, 36-56.

Abdullah A. & Khalil A. (2010) - *Rain Quality in Mosul City Afaf*. Journal of Research of the College of Basic Education, **3**: 398–413.

Aghazadeh N. & Mogaddam A. A. (2010) - *Assessment of groundwater quality and its suitability for drinking and agricultural uses in the Oshnavieh Area, Northwest of Iran*. Journal of Environmental Protection, **1**(01): 30.

Al-Dabbagh A. H. & Al-Youzbakey K. T. (2021) - *Geochemical Assessment of Heavy Elements in Sediments of main Wadis of Western Part of Mosul City, Iraq*. Italian Journal of Engineering Geology and Environment, **2**: 5–16. https://doi.org/10.4408/IJEGE.2021-02.O-01

Al-Dabbagh T. H. & Al-Naqib S. Q. (1991) - *Tigris River terrace mapping in northern Iraq and the geotechnical properties of the youngest stage near Dao Al-Qamar village.* Geological Society, London, Engineering Geology Special Publications, **7**(1): 603–609.

Al-Hayali A. K. A. (2010) - *Studying the Groundwater Quality in Mosul city and Showing the Range of their Suitability for Drinking and Irrigation*. Journal of Education and Science, **23**(3): 10–20.

Al-Jumaily I. S. I. & Al-Azzawi A. G. N. (2018) - *Structural and Tectonic Analysis of Bashiqa and AL-Fadhlya Anticlines- Northern Iraq*. Iraqi National Journal of Earth Sciences, **18**(1): 87-116.

Al-Naqib S. Q., Al-Youzbakey K. T. & Suleman A. M. (2018) - *Hydrochemistry and Groundwater Level Fluctuations (2009-2011) in Selected Wells at the Eastern Part of Mosul City, Northern Iraq*. The 9th Periodical Scientific Conference of Dams and Water Resources Research Center. Mosul University, Iraq, 28-29 November 2018: 19-34.

Al-Ozeer A. Z. A. A. & Ahmed M. F. (2019) - *Groundwater assessment at east side of Mosul City during 2014–2017* (pp. 35–48). Scientific Review Engineering and Environmental Sciences, **28** (1): 35–48. http://iks.pn.sggw.pl/

Al-Qassab I. M. H. (1987) - *Education Atlas of Iraq*. Dar Al-Kutub for Printing and Publishing, University of Mosul.

Al-YouzbakeY. K. T. & Sulaiman A. M. (2021) - *Assessment of water quality along Greater Zab River within Iraqi lands.* Italian Journal of Engineering Geology and Environment, **1**: 5–17.

Al-Yousbakey K. T., Sulaiman A. M. & Ismaeel D. A. (2018) - *The evaluation of chemical characterization for selected wells water in Mosul-Bahshiqa-Shalalat areas, Ninevah governorate, Northern Iraq.* The 9th Periodical Scientific Conference of Dams and Water Resources Research Center. Mosul University, Iraq, 28-29 November 2018: 201-216..

Al-Youzbakey K. T. & Sulaiman A. M. (2012) - *Aestimatio causalis aquae in area Telkaif-Alqosh, Mosul, Iraquia Septentrionalis*. Octavum periodicum colloquium scientificum de Matribus et Aquarum Resources Research Centrum: 155–164.

Al-Youzbakey K. & Sulaiman A. (2020) - *Ground Water Quality of Selected Areas in the Northeastern Mosul City and their Assessments for Domestic and Agricultural Usage*. Iraqi National Journal of Earth Sciences, **20**(1): 107–126.

Bordalo A. A., Teixeira R. & Wiebe W. J. (2006) - *A water quality index applied to an international shared river basin: the case of the Douro River*. Environmental Management, **38**(6): 910–920.

Chapman D. (1996) - *Water quality assessments: a guide to the use of biota, sediments, and water in environmental monitoring*. UNESCO/WHO/UNEP. University Press Cambridge, E & FN Spon, 626 pp.

Chu K., Liu W., She Y., Hua Z., Tan M., Liu X., Gu L. & Jia Y. (2018) - *Modified principal component analysis for identifying key environmental indicators and application to a large-scale tidal flat reclamation.* Water, **10**(1): 69.

Davis S. N. & Dewiest R. J. M. (1966) - *Hydrogeology,* John Wiley, and Sons, Inc, New York, 463 pp.

Ewaid S. H., Abed S. A. & Al-Ansari N. (2019) - *Crop water requirements and irrigation schedules for some major crops in Southern Iraq*. Water, **11**(4): 756.

Federation W. E. (2012) - APHA, AWWA, W.E.F. "*Standard Methods for examination of water and wastewater.*" In Anales de Hidrología Médica, **5**(2): 185-186.

Fouad S. F. A. (2015) - *Tectonic map of Iraq*, scale 1: 1000 000, 2012. Iraqi Bulletin of Geology and Mining, **11**(1): 1–7.

Gill R. (2014) - *Modern Analytical Geochemistry: an introduction to quantitative chemical analysis techniques for Earth, environmental, and materials scientists.* Routledge.

Gupta R. & Misra A. K. (2018). *Groundwater quality analysis of quaternary aquifers in Jhajjar District, Haryana, India: Focus on groundwater fluoride and health implications.* Alexandria Engineering Journal, **57**(1): 375–381. https://doi.org/10.1016/j.aej.2016.08.031

Hamill L. & F.G. Bell (1986) - *Groundwater Resource Development*, Butter werths ; London, 344 pp.

Hussein Al-Salim T. & Yaqup Matte L. (2009) - *Ground Water Quality of Areas Selected NE of Mousl City Used For Irrigration and Drinking Purposes.* In AL-Rafdain Engineering Journal (AREJ), **17**(3): 50–59. https://doi.org/10.33899/rengj.2009.40093

Hussein M. T. (2004) - *Hydrochemical evaluation of groundwater in the Blue Nile Basin, eastern Sudan, using conventional and multivariate techniques*.

Hydrogeology Journal, **12**(2): 144–158.

IQS 417, D.-W. S. (2001) - 417. *Central Organization for Quality Control and Standardization, Council of Ministers, Republic of Iraq.*

Kachroud M., Trolard F., Kefi M., Jebari S. & Bourrié G. (2019) - *Water quality indices: Challenges and application limits in the literature*. Water, **11**(2): 361.

Kannel P. R., Lee S., Lee Y. S., Kanel S. R. & Khan S. P. (2007) - *Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment.* In Environmental Monitoring and Assessment, **132**(1–3): 93–110. https://doi.org/10.1007/s10661-006-9505-1.

Kožíšek F. (2003) - *Health significance of drinking water calcium and magnesium*. National Institute of Public Health, **29**: 9285–9286.

Li P., Abbasi, T. & Abbasi S. A. (2014) - *Water Quality Indices*. https://doi.org/10.1007/s12665-014-3141-9 REVIEWS

Manahan E. S. (2010) - *Enviromental Chemistry*. 9th edition, Boca Raton, FL, USA, CRC Press, 783 pp.

Mason B. (1966) - *Principals of Geochemistry.* 3rd Edition. Willey International Publication, 324 pp.

Medici G. & Langman J. B. (2022) - *Pathways and Estimate of Aquifer Recharge in a Flood Basalt Terrain; A Review from the South Fork Palouse River Basin (Columbia River Plateau, USA)*. Sustainability, **14**(18): 11349. https://doi.org/10.3390/su141811349

Milovanovic M. (2007) - *Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe.* Desalination, **213**(1–3): 159–173.

Mohammed H. A. & Ismail S. F. (2021) - *Design and implementation of remotely monitoring system for Ph level in Baghdad drinking water networks*. Telkomnika, **19**(3): 1030–1038.

Mohammed H., Fadhil T. & Ismail S. (2018) - *Design and Implementation of Remotely Monitoring System for Total Dissolved Solid in Baghdad Drinking Water Networks*. Advances in Science, Technology and Engineering Systems Journal, **3**(1): 288-289- www.astesj.com

Mohammed. S. I. & Abdulrazzaq. K. A. (2018) - *Developing Water Quality Index to Assess the Quality of the Drinking Water Shahad.* Domestic Engineering Journal, **10**(4): 2345–2355.

Nova Scotia Environment. (2022) - Department of Environment and Climate Change.. Retrieved August 5. https://novascotia.ca/nse/

Rana R. & Ganguly R. (2020) - *Water quality indices: challenges and applications-an overview.* Arabian Journal of Geosciences, **13**: 1190. https://doi.org/10.1007/s12517-020-06135-7

Sahoo, M. M., Patra, K. C. & Khatua K. K. (2015) - *Inference of water quality index using ANFIA and P.C.A*. Aquatic Procedia, **4**: 1099–1106.

Sanders L. L. (1998) - *Manual of field hydrogeology*. Prentice Hall.

Sawyer C.N. & McCarty P.L. (1978) - *Chemistry for Environmental Engineering.* International Student Edition, McGraw-Hill Book Company, 3rd Edition, 518 pp.

Schuh W. M., Klinkebiel D. L., Gardner J. C. & Meyer R. F. (1997) - *Tracer and nitrate movement to groundwater in the Northern Great Plains.* Wiley Online Library.

Souad A. & Hassan M. S. (1990) - *Practical engineering for the environment, water testing*. Dar Al-Hikma for Printing and Publishing Mosul, 5-293

Sun W., Xiaa C., Xua M., Guoa J. & Sun G. (2016) - *Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River*. Ecological Indicators, **66**: 306–312.

Taha H. H. & Hussein M. Z. (2011) - *Classification of groundwater type, pilaspi quality by using Kohonen neural network*. Iraqi Journal of Statistical Sciences, **11**(2): 589–611.

Taha H. H. & Hussein M. Z. (2012) - *Using the Cluster Analysis to Classify the Quality of Ground Water in Wells of Bashiqa Region in Governorate of Ninaveh ABSTRUCT,* Iraqi Journal of Statistical Sciences, **21**: 215–233.

Tóth J. (1970) - *A conceptual model of the groundwater regime and the hydrogeologic environment. Journal of Hydrology,* **10**(2): 164–176.

Tyagi S., Sharma B., Singh P. & Dobhal R. (2013) - *Water quality assessment in terms of water quality index*. American Journal of Water Resources, **1**(3): 34–38.

Walton W. C. (1970) - *Groundwater resource evaluation*. McGraw-Hill Series in Water Resources and Environmental Engineering (U.S.A.) Eng.

WHO (2006) - *World Health Organisation: Guidelines for drinking water quality*, Third Edition, Vol. 1. Recommendations. In Environmental Pollution Series A, Ecological and Biological, **1**: 1–564. https://www.who.int/water_sanitation_health/dwq/GDWQ2004web.pdf

WHO (2016) - *World Health Organisation : Nitrate and Nitrite in Drinking-Water*. Geneva, Switzerland. 324 pp.

Zeinalzadeh K. & Rezaei E. (2017) - *Determining spatial and temporal changes of surface water quality using principal component analysis.* Journal of Hydrology: Regional Studies, **13**: 1–10.

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